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Axial vs Transverse Bunching in Sheet Beam TWTs

Thomas M. Antonsen Jr.

SAIC and University of Maryland
IREAP, University of Maryland,
College Park, MD 20742, USA
(antonsen@umd.edu)

Simon J. Cooke

Baruch Levush

Naval Research Laboratory, Code 6841,
4555 Overlook Avenue S.W.,
Washington, DC 20375, USA

Yuri N. Pchelnikov

SloWaveS, Inc., Cary, NC

Abstract: *We describe the linear theory for interaction between a sheet electron beam and a traveling wave, including space-charge effects, for both axial and transverse bunching.*

Keywords: sheet-beam; traveling-wave-tube; linear theory

Introduction

The goal of producing high power millimeter wave amplifiers based on sheet beam technology [1,2,3,4,5,6] requires designing slow wave structures that will couple strongly to planar electron beams [7]. We consider two aspects of the problem that will affect the gain and efficiency of such devices. The first is the competition and trade-offs between the axial bunching (O-type) upon which most TWT interactions are based, and the transverse (M-type) bunching that can occur when there are strong transverse fields and the beam is not rigidly confined in the transverse direction. The second issue we consider is the design of structures with the desired properties of subluminal phase velocity, high coupling impedance, and uniform interaction fields in the long transverse direction of the sheet beam.

To address the first issue we have performed a small signal analysis of the gain for a sheet electron beam, including transverse motion in a linear focusing force, and including space charge effects. The analysis is applied to a planar beam that is assumed to be in laminar equilibrium with the focusing force and that interacts with a slow wave whose axial electric field has either even or odd parity with respect to the mid-plane of the beam. In the even parity case the dominant bunching mechanism is O-type, while in the odd parity case the dominant bunching mechanism is M-type. Both situations lead to similar dispersion relations, but with different coefficients.

Theory

In the basic model, the AC electric field is separated into a structure component and a space charge component. The amplitude of the structure component is determined by projecting the beam current onto the mode of the cold structure. The phase velocity of the wave is assumed to be much below the speed of light. Consequently the total field

is approximately electrostatic. Solving for the space charge field, the beam current density and then projecting the current density onto the structure field results in the following dispersion relation,

$$(k - k_0) = -\frac{\omega}{2kc} Z' \frac{(1 - \epsilon_b) L_y \sinh(k\Delta)}{1 - R(1 - \epsilon_b)}.$$

Here ω is the frequency, k is the axial wave number, k_0 is the cold structure wave number, L_y is the long transverse beam dimension, Δ is the short transverse beam dimension, and the beam dielectric function is given by

$$\epsilon_b = \left(1 - \omega_b^2 / (\omega - kv_{z0})^2\right).$$

The quantities Z' and R represent the coupling impedance and space charge reduction factor. These depend on the parity of the modes,

$$Z' = \frac{1}{A_{eff}} \left| \frac{e_{z,RF}(kx_w)}{\cosh(kx_w)} \right|^2 \text{ or } \frac{1}{A_{eff}} \left| \frac{e_{z,RF}(kx_w)}{\sinh(kx_w)} \right|^2.$$

Where the first equality applies for even modes and the second for odd modes. The space charge reduction factors are given by,

$$\frac{2R}{\sinh(k\Delta)} = \begin{cases} \tanh(kx_w) - \tanh(k\Delta/2) & \text{even} \\ \coth(k\Delta/2) - \coth(kx_w) & \text{odd} \end{cases}.$$

The ratio of the reduction factors is,

$$R_{odd} / R_{even} = \frac{1}{\tanh(k\Delta/2) \tanh(kx_w)}.$$

Note that this ratio is always greater than one, and will be significantly greater than one in the case in which either the structure or the beam is thin compared to an axial wavelength. This however, is the case of interest as making the structure thin is required to keep the interaction impedance high, and the beam must be small compared to the thickness of the structure.

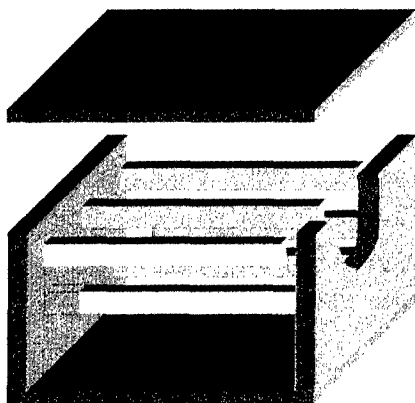


Figure 1. Planar comb structure

We have analyzed a number of different planar structures that are suitable for sheet beam interaction. These include aligned combs [7] offset combs, symmetric and asymmetric fingered structures of the type shown in Fig. 1.

While these structures can provide waves with the correct phase velocity, they tend to have small axial fields and thus small coupling impedances. Finally, a promising option is a coupled-cavity model with capacitively-coupled sides as depicted in Fig. 2. In this structure the capacitively coupled slides reduce field shorting to the wall and allow for a high interaction impedance. Additionally, the slots can be tuned to increase the flatness of the field allowing all portions of the beam to interact with the mode. Further, this structure can be fabricated without cantilevers or ceramic supports and will be investigated in more detail.

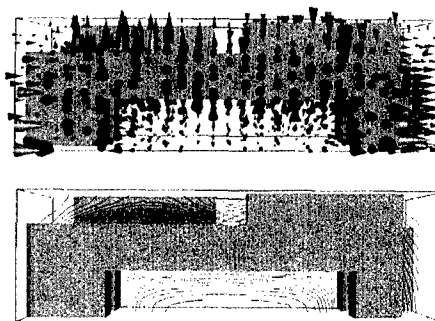


Figure 2. Coupled cavity structure with three slots.

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